

Transport Studies of Lactic Acid Through Supported Liquid Membrane

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The aim of this study is to present transport of lactic acid through contained supported liquid membrane (CSLM). The liquid membrane carriers used were Alamine 336 and TBP. The formation of acid amine and solvation or ion pair complexes are dominating factors for the transport of lactic acid through liquid membrane. Diluting solvent used in this study is toluene. The permeability coefficient was calculated from the experimental results and interpreted for dependency on experimental variables. Different experimental variables investigated were stirring of source and receiving bulk phases, effect of pH of source phase, effect of sodium hydroxide concentration in receiving phase, TBP or Alamine 336 concentration in membrane phase, lactic acid concentration in source phase, etc. The pre-concentration of lactic acid has been investigated in the concentration range 10^{-6} to 10^{-2} mol L⁻¹. The transport of lactic acid has been studied for individual as well as combined system of Alamine 336 and TBP. It was observed that mixed extractants system of Alamine 336 and TBP is more effective for transport of lactic acid from source to receiving phase. The stability of CSLM system observed was quite good for the period of 50 h.

Keywords:

Lactic acid, Alamine 336, liquid membrane, transport by combined effect, Tributyl phosphate, pre-concentration.

Introduction

The liquid membrane technique has been used for transport studies of organic compounds.^{1–2} It has several advantages over conventional solvent extraction and ion exchange methods. Among the liquid membrane techniques, bulk, SLM (supported liquid membrane) and emulsion membranes have been systematically investigated. Although, SLM technique suffers from its instability problem in view point of industrial large-scale operation and continuous applications, it can be eliminated with advancing further research investigations. In recent years, there are interesting studies coming up in this field. It has been reported about the contained supported liquid membrane technique.³ Although, this technique increases the diffusion process path in the liquid membrane phase, it may help to increase the stability of SLM system in the long run continuous operations. In this system, the extracting organic solvents are contained in between and on the well-packed micro-porous membrane supports, and the extractant can be supplied from external reservoir if necessary by micro design arrangement.³

Majority of organic compounds are separated by column chromatography based on adsorption-desorption process. Moreover, solvent extraction is also used to separate some organic compounds based on solubility and complex formation mecha-

nism. However, solvent extraction technique has several disadvantages. Membrane technique has emerged as advanced separation technique for organic compounds.^{4–9} Lactic acid is a fermentation product of lactose. It is present in sour milk, koumiss, leban, yogurt and cottage cheese. The protein in milk is coagulated by lactic acid. Lactic acid is produced in the muscles during intense activity. Calcium lactate, a soluble lactic acid salt, is used as a source of calcium in the diet. Lactic acid is produced commercially for use in pharmaceuticals and foods, in leather tanning and textile dyeing, and in making plastics, solvents, inks, and lacquers. Although, it can be prepared by chemical synthesis, production of lactic acid by fermentation of glucose and other substances is a less expensive method. Thus lactic acid is an important compound; therefore, it is worthwhile to study the ion transport of lactic acid through liquid membrane.

CSLM structure allows the liquid membrane phase with independent control of pressure with the spring action and flexibility of movement due to the two supported liquid membranes without keeping empty space. The solubility of liquid membrane phase in aqueous phases is one of the reasons of stability of liquid membrane. The CSLM structure allows independent control of pressure in each phase (aqueous or organic). Maintaining the proper phase pressures is the chief requirement for suc-

cessful operation. For hydrophilic supports with aqueous phase in the porous support wall pores, the pressure of the organic liquid membrane must be higher than that of the aqueous phases. For hydrophobic supports with the organic liquid membrane in the pores, the reverse is true. In both the cases, the pressure differential between the phases must be less than the breakthrough pressure.³

The different causes for the instability of supported liquid membrane are given here. The supported liquid membranes appear to be unstable under high osmotic pressure gradients. However, the instability effects are not caused by pressure difference, but rather they depend strongly on type of the solvent, flow velocity of aqueous phases, molecular structure of the carrier used, salt concentration in the stripping phase, emulsion formation induced by shear forces. In general, the high interfacial tension of liquid membrane provides more stable SLMs, but this relation is not unambiguous. Also no direct relation was found between the stability and the viscosity of the membrane phase. It was also concluded that the SLM lifetime depends also on the type of carrier-diluent mixture used as liquid membrane. All these observations are sometimes contradictory. This may be due to the fact that different systems were used to examine the instability effects.^{10–11}

The developed CSLM technique can offer a practical useful technique to current existing systems for removal and pre-concentration of several chemical species from aqueous source to receiving solution. This can be achieved either by a transport or co-transport or counter transport mechanism depending on the nature of chemical species to be transported, and the type of extractants being utilized.

Currently, a number of agro-processing and chemical companies are entering in the lactic acid market as they have or will soon be starting up large-scale fermentation processes to produce lactic acid from agriculture product. The combination of fermentation processes and separation processes^{12–34} would provide a clean route for the production of lactic acid. In the production of lactic acid, processes produce multicomponent, aqueous solutions with product of acid concentrations. Subsequent separation, purification and concentration of the acid recovery of carboxylic acids from fermentation broth, presents a challenging separation difficulties because of high affinities of the acids for water distillation of dilute, non-volatile acid involves large energy consumption for the heat of vaporization of water, which must be taken overhead, furthermore, distillation cannot fractionate among non-volatile acid.

Moreover, extraction studies of lactic acid in supported liquid membrane are lacking. The proposed liquid membrane system consists of using

commercial solvating and amine extractants. The goal of this paper is to study the transport of lactic acid. The mechanism of transport of lactic acid through supported liquid membrane has been illustrated. The comprehensive investigations on removal and pre-concentration of lactic acid from aqueous source solution to aqueous receiving solution by CSLM system have been carried out. The carriers used for these research activities were Alamine 336 and TBP (tributyl phosphate) in toluene. The systematic research studies include the experimental variables, such as concentration of carriers in the diluent toluene, pH of source solution, alkali concentration in receiving solution, and effect of lactic acid concentration.

Experimental

Reagents and apparatus

The solvating extractant TBP (tri-butyl phosphate) (Aldrich Chemicals CO, USA), and Alamine 336 (a mixture of straight chain tertiary amines with seven to nine carbon atoms, Henkel Co.), were used. The suitable concentrations of amine and solvating extractants were used to impregnate on the microporous polypropylene membrane supports. The thickness 10^{-2} cm in between two microporous supports was observed. The different concentrations of organic solutions were prepared by diluting a desired amount of extractant with toluene. Lactic acid solutions were prepared by dissolving an appropriate quantity of lactic acid in distilled water. The content of lactic acid in the solution was confirmed by titration with sodium hydroxide. Acid analysis was checked against a material balance. The solubility of amine salts and diluents in the aqueous phase were negligible in the range of variables investigated. All other chemical used were of analytical grade.

The experimental apparatus used in this investigation to measure the permeability coefficient (P) is described in Fig. 1. A membrane (SLM) with an interfacial area of 11.94 cm^2 was used. The variation of lactic acid concentration with respect to time

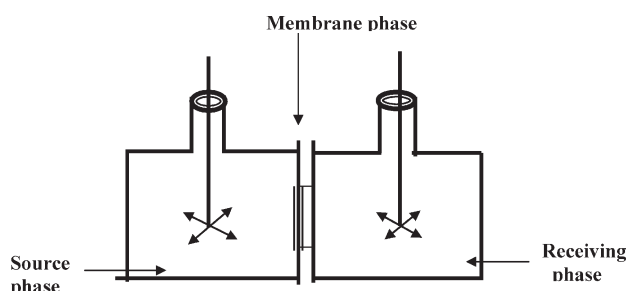


Fig. 1 – Schematic representation of apparatus used for measurement of permeability coefficient of lactic acid.

was estimated using samples drawn from the source and receiving solutions with titration with sodium hydroxide. The pH measurement of source solution was done with pH meter. The concentration of the acid in aqueous phase was analyzed by HPLC (Waters Associates, Milford MA USA) with a LiChrospher 100 RP-18 column (Merck, 5 μm) and UV detector at 254 nm. The reproducibility of the experiment was checked with the experimental results of means of two reproducible runs.

Preparation of supported liquid membrane

A membrane 2500 (Celenease Co., USA), which is a microporous polypropylene membrane of thickness 2.5×10^{-3} cm, average pore diameter 0.04 μm , porosity 45 % was used as the supporting membrane for immobilization of mixed extractants in toluene. The membrane supports were immobilized with carriers by soaking (The soaking of amine and solvating extractants solution was carried out under the suitable nitrogen pressure required in a sintered glass gooch crucible by keeping the required area membrane support and filtering very slowly the extractant solution through membrane support supported on sintered glass gooch crucible) it in a reformulated different amine and solvating extractants solution for 2 h. The amine and solvating extractants solution immobilized in the microporous support were determined to be about 0.1 ml by weighing the membrane before and after the immobilization. The total quantity of containing extractant in between supported membranes including immobilized on microporous membrane was found to be nearly 0.35 ml.

Procedure

A source solution with a suitable lactic acid concentration in 35 ml distilled water was put into the bigger cell. Using dilute solutions of hydrochloric acid or sodium hydroxide did its pH adjustment to the desired value whenever necessary. The receiving phase used 25 ml was with appropriate dilute sodium hydroxide. The source and receiving solutions, separated by SLM, were without leakage. The receiving solution was directly titrated with sodium hydroxide.

Results and discussions

Configuration of supported liquid membrane

A conventional solvent extraction system, which is carried out in two steps either for separation or pre-concentration of chemical species from its source solution, is illustrated in bulk solutions as shown in Fig. 2. A bulk liquid membrane system,

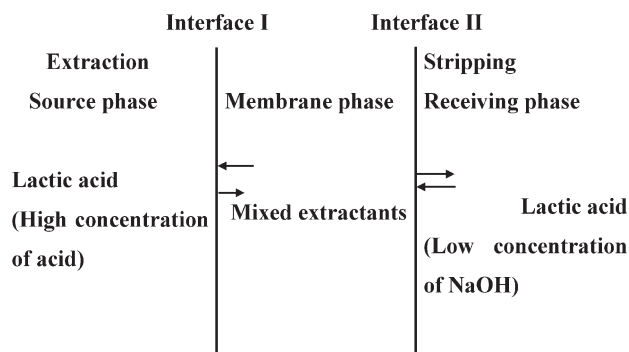


Fig. 2 – Representation of lactic acid transport in a supported liquid membrane.

which consists of source (s), membrane (m) and receiving (r) phases, is illustrated in Fig. 2. In the conventional solvent extraction technique, the extraction and stripping processes are carried out one after the other. However, during these processes, different modes of occurrence involved are dispersion of one phase as drops in another phase, subsequent to coalescence of dispersed phase and phase separation. This mode of operation frequently leads to solvent loss by emulsion formation. This may cause the loss of costly carriers or chelating agents and extractant loading. The dispersion free solvent extraction technique, i.e. membrane technique eliminates all such shortcomings. Fig. 2 illustrates the transport of lactic acid from source phase through liquid membrane to receiving phase. This lactic acid transport process can be represented by two extraction processes, namely, transport of lactic acid from the aqueous to organic phase as a forward extraction process, and lactic acid transport from organic phase to the aqueous phase as a backward extraction process. These extraction processes can be simultaneously carried out in contained supported liquid membrane extractor as extraction and stripping processes as explored in the present investigations.

Permeability is expressed as rate of change of concentration of lactic acid with respect to time in a cross section area and volume of source phase

$$J = -V_s \frac{1}{A} \cdot \frac{dc}{dt} \quad (1)$$

Where, V_s is the volume of the feed or source solution, A the membrane area and l the membrane thickness. After the integration of above equation becomes

$$\ln(c_t/c_0) = \frac{p}{l} \cdot \frac{A}{V_s} \cdot t \quad (2)$$

Where c_0 is the value of c_t at time zero, and p is permeability coefficient. To estimate thickness of

SLM or CSLM in microporous support, the geometric thickness of support is multiplied by tortuosity of pores.^{35–36} In case of our micro-porous polypropylene films SLM or CSLM thickness was found 6.2 mm. In this investigation, the results are presented in terms of P that is product of p , l and A .

Basically, in stagnant process,³⁷ transport of lactic acid in supported liquid membrane slowly takes place. However, it can be enhanced by allowing fast diffusion of lactic acid in bulk solutions and establishing fast consecutive step equilibrium concentration of chemical species in bulk solution, in order to proceed continuous chemical reactions at interfaces and bulk solutions. The adequate diffusion distribution of lactic acid in bulk solution was achieved with stirring independently source and receiving phases. However, in this supported system, the diffusion of chemical species in thin film membrane phase is taking place by itself without stirring membrane phase. Thus transport of lactic acid from source phase to receiving phase also depends on the time required for the diffusion of lactic acid in membrane phase. Dependency of lactic acid transport on involved chemical species and their concentration is investigated.^{37–38}

Variation of lactic acid concentration with time

Source and receiving phases were independently stirred. Sample solution from source and receiving phases with respect to time was taken and analyzed for lactic acid for TBP, Alamine 336 and TBP + Alamine 336 systems. The plot of $\log(c_t/c_0)$ vs. t is shown in Fig. 3. The value of P is determined by using Equation (2). Lactic acid concentration in source phase decreases, and receiving phase increases with respect to time for these TBP, Alamine 336 and TBP + Alamine 336 systems. The plot of $\log(c_t/c_0)$ vs. t shows that value of $\log(c_t/c_0)$ for TBP + Alamine 336 system is drastically decreased in comparison with that of TBP and

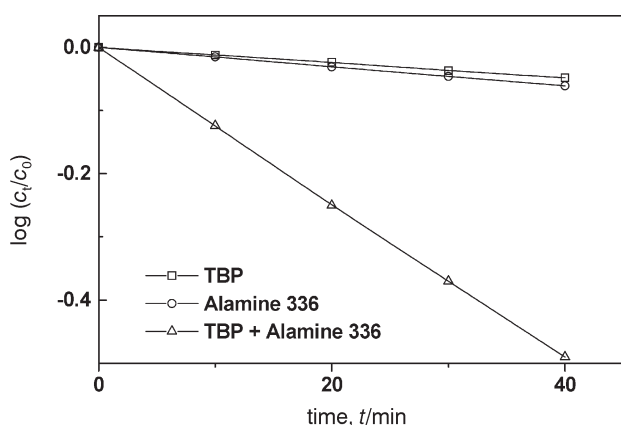


Fig. 3 – Plot of $\log c_t/c_0$ vs. time for lactic acid transport through supported liquid membrane.

Alamine 336. It shows that transport of lactic acid in mixed system is combined effect.

Effect of the stirring speed

In order, to explore the effectiveness and efficiency of transport of lactic acid in SLM system it is significant to investigate the effect of diffusion process and chemical reactions on fluxes of the transport of lactic acid. The effect of the stirring speed in bulk solution on the diffusion of lactic acid through bulk solution is also important factor, in order, to minimize the diffusion layer at the interfaces. The source and receiving phases were independently stirred over the range 40 to 130 rpm (Fig. 4). The permeability coefficient increases for the range of 40 to 90 rpm, which indicates that the thickness of diffusion layer decreases. However, the P values nearly remain constant during the range 90 to 130 rpm of stirring of the both phases. This region is responsible for the achievement of minimum diffusion layer thickness at the interfaces. Further, research studies were done at 100 rpm.

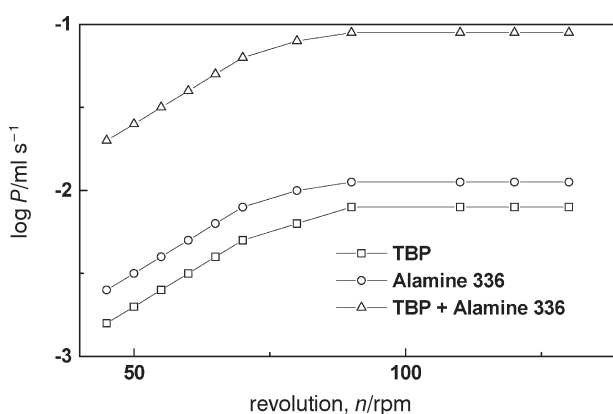


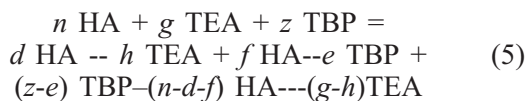
Fig. 4 – Effect of stirring speed of source and receiving phases on permeability coefficient (P) of lactic acid, $c_{\text{lactic acid}} = 0.01 \text{ mol L}^{-1}$, $c_{\text{Alamine 336}} = 0.1 \text{ mol L}^{-1}$, $c_{\text{TBP}} = 0.1 \text{ mol L}^{-1}$, $pH_s = 2.0$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$ and $A = 11.94 \text{ cm}^2$.

Transport of lactic acid at interfaces from one to the other phase is dependent on the concentration of chemical species in bulk phase and interface.^{10–11,37–38} However, concentration of chemical species in bulk phase and interface is assumed to be more or less the same. The influences of chemical species concentration on transport of lactic acid have been investigated.

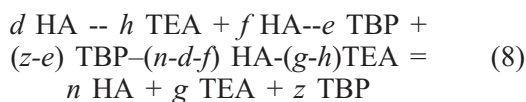
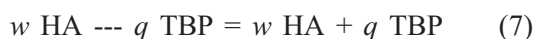
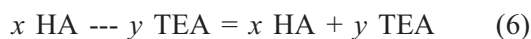
Reactions occurred at interfaces

Solvating solvent as extractant in liquid membrane plays a very important role. The solvating solvents such as TBP, TOPO, TTA, β -diketone, etc can be used in liquid membrane. The low aqueous activity of carboxylic acids results in low distribu-

tion coefficients of acid into conventional solvents. Thus, solvent extraction with conventional solvents would require very high solvent flow rates and result in substantial dilution of acid. Aliphatic tertiary amines dissolved in an organic solvent are useful extractants for carboxylic acids. The amine binds the acid in the organic phase through reversible complexation often; water is taking part in complex formation, thus having a strong influence on the liquid-liquid equilibrium. It has been found that solvating solvent, especially those with functional groups, can offer the extraction behavior of amine, significantly. The stoichiometry solute, amine complex, loading of amine as well as the third phase formation, are influenced by the diluents. The effect of solvating solvent can be understood in terms of ability to solvate organic phase species. Therefore, it is necessary to distinguish between general solvation from electrostatic dispersion or other forces, and specific solvation due to hydrogen bonding. The extraction of carboxylic acids with tertiary amine or TBP usually occurred due the formation of ion-pairs and hydrogen bonds.^{39–41} The extraction processes can be described by the reactions at interface I with lactic acid, $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$, (HA) and Alamine 336 (TEA) or TBP or with mixture of them. The HA (lactic acid), TEA (Alamine 336) and TBP are used for convenient purpose to illustrate extraction and stripping mechanism.



The stripping processes can be described by the complex breaking reactions at interface II. The formed free extractants are diffused back to interface I for further transport of lactic acid.



Effect of pH of source solution

In order to explore the significant role being played by hydrogen ion concentration in the source solution during the permeation of lactic acid in SLM system, the permeation studies were carried out at different pH of the source solution. The relation between P and pH of the source solution has

been illustrated in the Fig. 5a. The increase in P value along with the decrease in the pH was observed for 1.5 to 5.5. Log p values increases with the decrease in pH of source solution, because of favored formation of strong hydrogen bonding, and

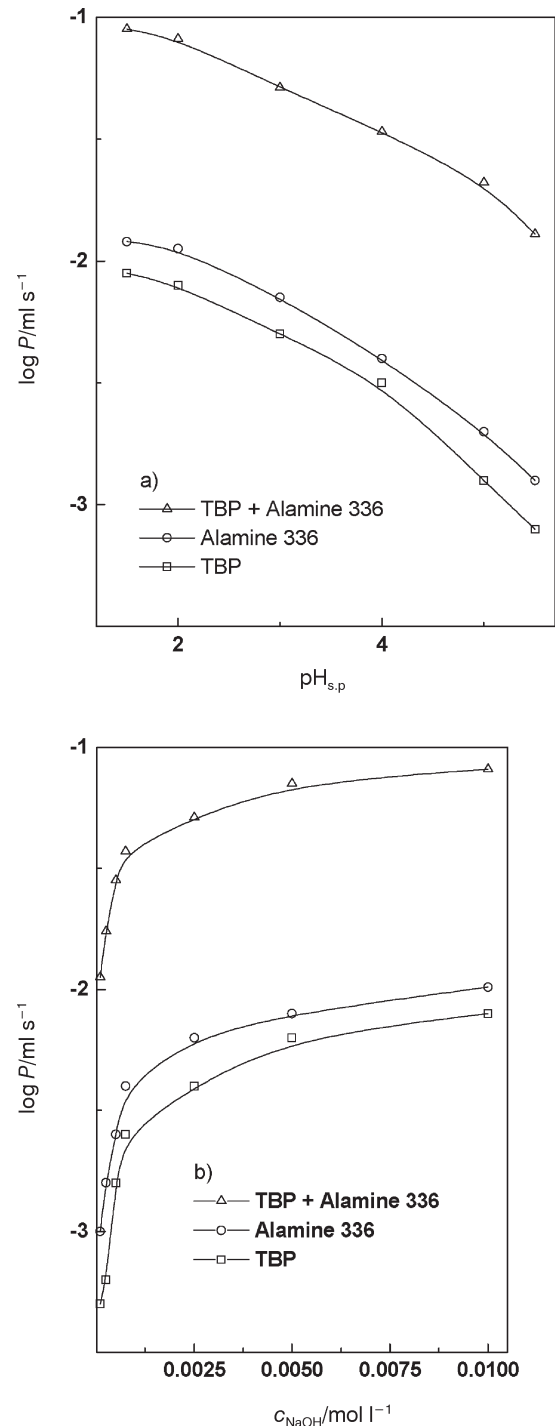


Fig. 5 – (a) The relation between P and pH of the source solution, $c_{\text{lactic acid}} = 0.01 \text{ mol L}^{-1}$, $c_{\text{Alamine 336}} = 0.1 \text{ mol L}^{-1}$, $c_{\text{TBP}} = 0.1 \text{ mol L}^{-1}$, $c_{\text{NaOH}} = 0.01 \text{ mol L}^{-1}$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$ and $A = 11.94 \text{ cm}^2$; (b) The relation between P and sodium hydroxide concentration of receiving solution, $c_{\text{lactic acid}} = 0.01 \text{ mol L}^{-1}$, $c_{\text{Alamine 336}} = 0.1 \text{ mol L}^{-1}$, $c_{\text{TBP}} = 0.1 \text{ mol L}^{-1}$, $\text{pH}_s = 2$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$ and $A = 11.94 \text{ cm}^2$.

increased formation of ion-pair complexes with the decrease in pH of source solution. Therefore, the transport of lactic acid is favored with the decrease in pH of source solution. However, higher $\log P$ values are observed for the Alamine 336 + TBP system in comparison with that of single Alamine 336 or TBP system.

Effect of sodium hydroxide concentration in the receiving phase

The solution of sodium hydroxide is used in receiving phase in order to make reaction of sodium hydroxide with lactic acid for making salt solution. The solution of sodium hydroxide is required to eliminate the lactic acid liquid phase mass-transfer resistance, which probably affected the lactic acid permeation through supported liquid membrane. In general, the extraction of lactic acid occurs at the higher hydrogen ion concentration in comparison to that of stripping process. In order to strip out the lactic acid from membrane phase, it is necessary to reduce hydrogen ions and make less competitive to lactic acid during the stripping process towards extractants. Thus, with the decrease in acid concentration in receiving solution, and increasing the concentration of alkali in receiving phase, the distribution ratio of lactic acid decreases at the stripping side. However, to check the sodium hydroxide concentration effect on stripping out the lactic acid from membrane phase, the sodium hydroxide concentration of receiving solution was varied from 0.0001 to 0.01 mol L⁻¹ range (Fig 5b). The P value decreases along with a decrease in the sodium hydroxide concentration of the receiving solution. It is concluded that the chemical resistance in aqueous receiving solution during the stripping process decreases along with an increase in its sodium hydroxide concentration.

Effect of the carrier concentration

The carrier plays a significant role during the permeation of lactic acid in the SLM system in viewpoint of its economical viability, effective transport, stability, industrial applications, etc. It is, therefore, significant to investigate the effect of the Alamine 336 concentration on the permeation of lactic acid. The variation of concentration of Alamine 336 was carried out over the range from 10⁻⁵ to 0.1 mol L⁻¹. The permeability co-efficient of lactic acid increases along with an increase in the Alamine 336 concentration over the studied range (Fig. 6 a). The variation of concentration of TBP was investigated over the range from 10⁻⁵ to 0.1 mol L⁻¹. The permeability co-efficient of lactic acid increases along with an increase in the TBP concentration over 10⁻⁵ to 0.1 mol L⁻¹ range (Fig. 6

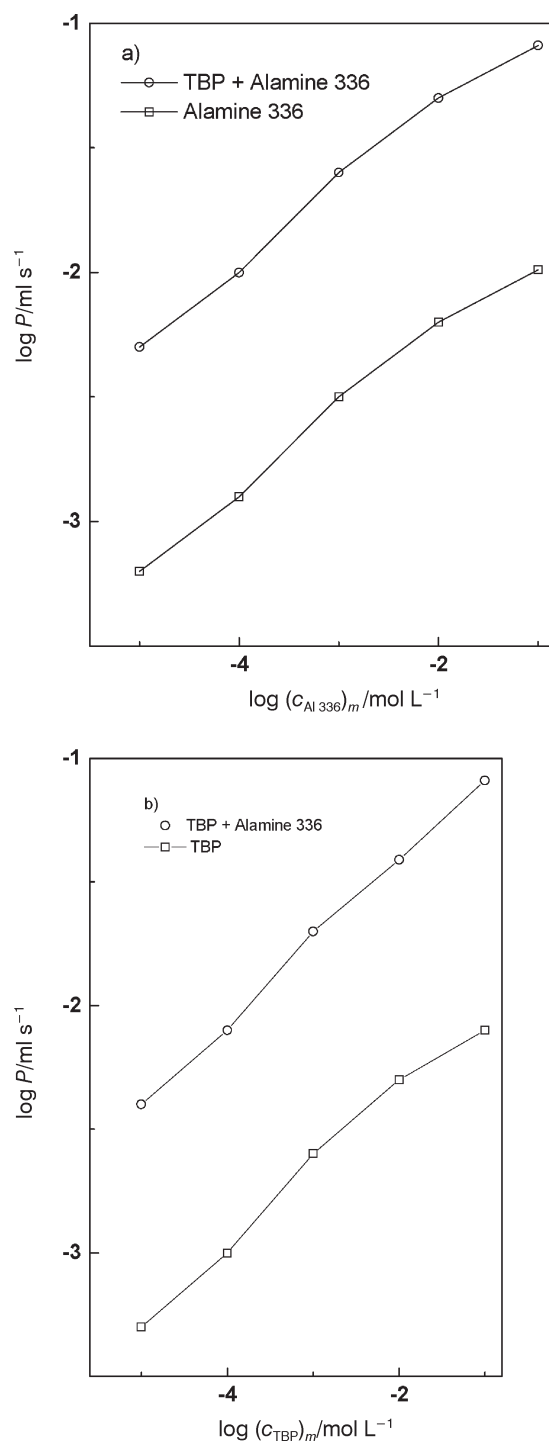


Fig. 6 – Effect of concentration of carrier on permeability coefficient (P) of lactic acid, (a) $c_{\text{lactic acid}} = 0.01 \text{ mol L}^{-1}$, $c_{\text{Alamine 336}} = 0.1 \text{ mol L}^{-1}$, $\text{pH}_s = 2$, $c_{\text{NaOHr}} = 0.01 \text{ mol L}^{-1}$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$, $A = 11.94 \text{ cm}^2$ and TBP variation, (b) $c_{\text{lactic acid}} = 0.01 \text{ mol L}^{-1}$, $c_{\text{TBP}} = 0.1 \text{ mol L}^{-1}$, $\text{pH}_s = 2$, $c_{\text{NaOHr}} = 0.01 \text{ mol L}^{-1}$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$, $A = 11.94 \text{ cm}^2$ and Alamine 336 variation

b). It could be possible to explore its utility for the effective separation and pre-concentration of lactic acid at a maximum concentration of Alamine 336 and TBP, which makes the SLM system economically inexpensive, efficient, and rapid in compari-

son to that of liquid extraction. The hydrogen bond formation and solvation complex formation between lactic acid and Alamine 336 or TBP depends on concentration of carrier in membrane phase, hydrogen ion, and lactic acid concentrations in source phase. With the increased concentration of Alamine 336 or TBP in membrane, it was observed that the $\log P$ values were increased. The combined effect was observed for Alamine 336 + TBP system. The combined effect of Alamine 336 and TBP enhances the transport of lactic acid in comparison with that of individual system.

Effect of the lactic acid concentration

It is essential to explore the effect of lactic acid concentration during the lactic acid transport in SLM system in order to exploit these investigations for the purpose of separation and pre-concentration of lactic acid. The variation of lactic acid concentration during these studies has been done over the 10^{-6} to 10^{-2} mol L⁻¹ range (Fig. 7). At lower concentration of lactic acid, the $\log P$ values remain nearly independent in the concentration range of lactic acid 10^{-6} to 10^{-2} mol L⁻¹. However, above this concentration range, it starts decreasing due to loading capacity of extractant in membrane phase. Moreover, in combined extractants system of TBP and Alamine 336, the $\log P$ value was much higher than that of individual system of Alamine 336 or TBP system. The pre-concentration of the lactic acid can be done in an efficient way from dilute solutions.

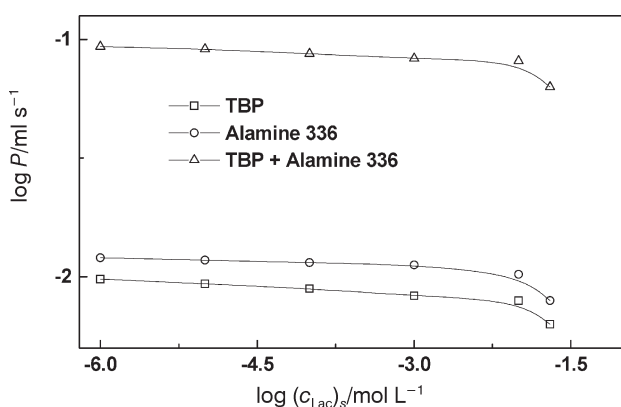


Fig. 7 – The dependency of P on lactic acid concentration in source solution, $c_{\text{Alamine 336}} = 0.1 \text{ mol L}^{-1}$, $c_{\text{TBP}} = 0.1 \text{ mol L}^{-1}$, $\text{pH}_s = 2$, $c_{\text{NaOH}} = 0.01 \text{ mol L}^{-1}$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$ and $A = 11.94 \text{ cm}^2$

Pre-concentration of lactic acid in CSLM system

The enrichment factor (EF) is the ratio of lactic acid concentration in source to receiving phase at time t . EF has been used to evaluate efficiency of supported liquid membrane system. The effect of variation of initial lactic acid concentration in

source solution was explored from 10^{-7} to 10^{-2} mol L⁻¹. The variation in the enrichment factor (EF) value with respect to initial lactic acid concentration in source solution has been illustrated in Fig. 8. The EF value decreases with increase in the initial lactic acid concentration in the source solution. This may be due to the increase in the source solution with relatively high lactic acid concentration; the lactic acid transfer was hindered due to the limited loading capacity of the carriers in the membrane phase, and increased viscosities in the aqueous and membrane phases. The low rate of mass transfer due to diffusion and chemical reaction processes which account for the chemical resistances in aqueous and membrane phases. Thus, effective and efficient pre-concentration of lactic acid can be carried out from dilute solutions.

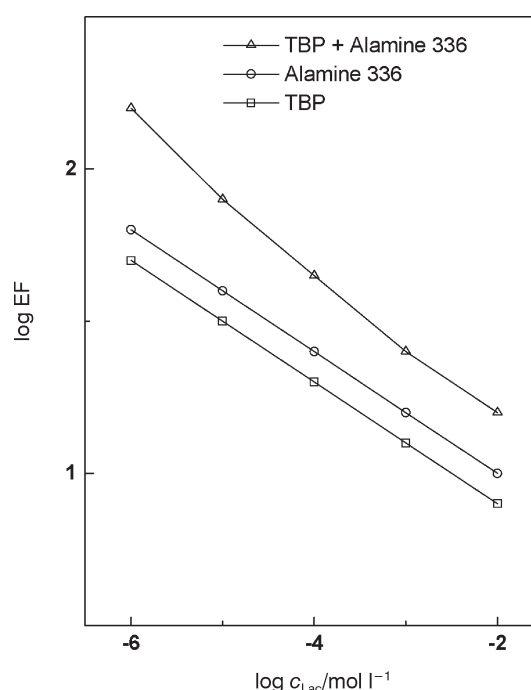


Fig. 8 – Representation of pre-concentration of metal ion from source to receiving solution, $c_{\text{Alamine 336}} = 0.1 \text{ mol L}^{-1}$, $c_{\text{TBP}} = 0.1 \text{ mol L}^{-1}$, $\text{pH}_s = 2$, $c_{\text{NaOH}} = 0.01 \text{ mol L}^{-1}$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$ and $A = 11.94 \text{ cm}^2$

Stability of CSLM

The stability of polypropylene support has been checked under the feasible conditions of CSLM system. The CSLM system has been continuously used for 50 h (Fig 9). During these hours of experiments, the P value remains unaffected. The small decreased P value can be attributed towards the increased membrane resistance to the permeation of lactic acid. The durability of microporous polypropylene support has been found satisfactory. The effective transport of lactic acid has been observed with Alamine 336 + TBP system.

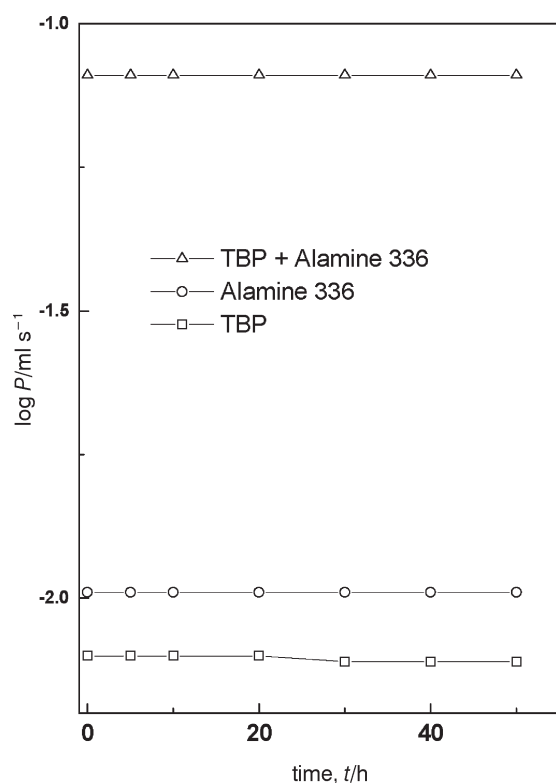


Fig. 9. – The presentation of stability of SLM system, $c_{\text{lactic acid}} = 10^{-3} \text{ mol L}^{-1}$, $c_{\text{Alamine 336}} = 0.1 \text{ mol L}^{-1}$, $c_{\text{TBP}} = 0.1 \text{ mol L}^{-1}$, $\text{pH}_s = 2$, $c_{\text{NaOHr}} = 0.0001 \text{ mol L}^{-1}$, $V_s = 35 \text{ ml}$, $V_m = 0.35 \text{ ml}$, $V_r = 25 \text{ ml}$ and $A = 11.94 \text{ cm}^2$

Conclusions

The transport of lactic acid in a CSLM system consisting of source, membrane and receiving phases has been carried out. The membrane phase used was mixture of or individual extractant Alamine 336 or TBP in diluent toluene. The experimental results show that transport of lactic acid depends on different experimental parameters such as stirring speed of bulk phases, pH of source phase, NaOH concentration in receiving phase, concentration of carrier in membrane phase, lactic acid concentration in source phase, etc. In CSLM system, the membrane phase can be allowed to pressurize independently in atmosphere pressure. It shows, the flexibility and spring action of liquid membrane phase to the source and receiving phase, exerted pressure. It may help to increase the lifetime of CSLM system. The enrichment of lactic acid can be achieved from dilute solution. The stability of proposed membrane system observed was for 50 h.

List of symbols

A – membrane area, cm^2
 c_{La} – concentration of lactic acid, mol L^{-1}
 F – volume flow rate, mol s^{-1}

l – membrane thick, mm
 p – permeability coefficient, $\text{cm}^2 \text{ s}^{-1}$
 P – volume flow rate, mL s^{-1}
 t – time, s
 V – volume, mL

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